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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No. AWR-017 (457/19)
 First Named Inventor Tzannes
 Title A System And Method For Scrambling The Phase Of
 The Carriers In A Multicarrier Communications
 System

APPLICATION ELEMENTS

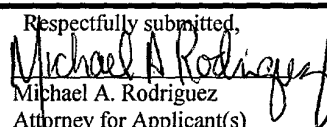
ADDRESS TO: **Box Patent Application**
Assistant Commissioner for Patents
Washington, D.C. 20231

1. ☒ Fee Transmittal Form
2. ☒ Specification and Drawings [Total Pages 27]
 X - Written Description - (18 pages)
 X - Claims - (6 pages)
 X - Abstract - (1 page)
 X - Sheets of Drawings - (2 sheets)
☐ Formal
☒ Informal
3. ☒ Oath or Declaration [Total Pages 3]
 a. ☒ Newly executed (original)
 b. ☐ Copy from a prior application (37 CFR 1.63(d))
(for continuation/divisional with Box 17 completed)
[Note Box 4 below]
4. ☐ Incorporation by Reference (usable if Box 3b is checked)
 The entire Disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 3b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
5. ☐ Microfiche Computer Program (Appendix)
6. ☐ Nucleotide and/or Amino Acid Sequence Submission
☐ Computer Readable Copy
☐ Paper Copy (identical to computer copy)
☐ Statement verifying identity of above copies
7. ☐ 37 CFR 3.73(b) Statement (when there is an assignee)
☐ Power of Attorney
8. ☐ English Translation Document (if applicable)
9. ☐ Information Disclosure Statement (IDS)/PTO-1449
☐ Copies of IDS Citations
10. ☐ Preliminary Amendment
☐ Drawings [Total Sheets]
☐ Letter to Official Draftsperson Including Drawings [Total Pages]
11. ☒ Return Receipt Postcard
12. ☐ Small Entity Statement(s)
☐ Statements filed in prior application, (Status still proper and desired)
13. ☐ Certified Copy of Priority Document(s)
14. ☐ Deletion of Inventor(s)
 Signed statement attached deleting inventor(s) named in the prior application.
15. ☒ Patent Application Data Entry Form
16. ☐ Other:
17. ☐ If a **CONTINUING APPLICATION**, check appropriate box and supply the requisite information:
☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application Serial No. ____/____.
Priority to the above application(s) is claimed under 35 U.S.C. 120.
 Prior application information: Examiner: _____. Group/Art Unit: _____.
18. ☒ **Priority - 35 U.S.C. 119**
☒ Priority of application Serial No. 60/164,134 filed on November 9, 1999 in United States is claimed under 35 U.S.C. 119.
☐ The certified copy has been filed in prior U.S. application Serial No. ____/____ on _____.
☐ The certified copy will follow.

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ABRAMSON457/19.1105071

FEE TRANSMITTAL **FY 2001**

Complete if Known

Application Serial Number	Not Yet Assigned
Filing Date	Herewith
First Named Inventor	Tzannes
Group Art Unit	Not Yet Assigned
Examiner Name	Not Yet Assigned
Attorney Docket No.	AWR-017 (457/19)

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CORRESPONDENCE ADDRESS Direct all correspondence to: Patent Administrator Testa, Hurwitz & Thibault, LLP High Street Tower-125 High Street Boston, MA 02110 Tel. No.: (617) 248-7000 Fax No.: (617) 248-7100		SIGNATURE BLOCK Date: November 9, 2000 Reg. No.: 41,274 Tel. No.: (617) 248-7501 Fax No.: (617) 248-7100 Respectfully submitted, <i>Michael A. Rodriguez</i> Michael A. Rodriguez Attorney for the Applicants Testa, Hurwitz & Thibault, LLP High Street Tower-125 High Street Boston, MA 02110																																																																																							

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Application Information

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Title Line Two :: In A Multicarrier Communications System
Total Drawing Sheets :: 2
Formal Drawings :: No
Application Type :: Utility
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Contract Number ::
Grant Number ::
Secrecy Order in Parent Application ::

Representative Information

Representative Customer Number :: 021323

Continuity Information

This application claims the benefit of:
>Application One :: 60/164,134
Filing Date :: November 9, 1999

5

**A System and Method for Scrambling the Phase of the Carriers in a Multicarrier
Communications System**

Related Application

10 This application claims the benefit of the filing date of copending U.S. Provisional
Application, Serial No. 60/164,134, filed November 9, 1999, entitled "A Method For Randomizing
The Phase Of The Carriers In A Multicarrier Communications System To Reduce The Peak To
Average Power Ratio Of The Transmitted Signal," the entirety of which provisional application is
incorporated by reference herein.

15

Field of the Invention

This invention relates to communications systems using multicarrier modulation. More
particularly, the invention relates to multicarrier communications systems that lower the peak-to-
average power ratio (PAR) of transmitted signals.

Background of the Invention

20

In a conventional multicarrier communications system, transmitters communicate over a
communication channel using multicarrier modulation or Discrete Multitone Modulation (DMT).
Carrier signals (carriers) or sub-channels spaced within a usable frequency band of the
communication channel are modulated at a symbol (i.e., block) transmission rate of the system. An
input signal, which includes input data bits, is sent to a DMT transmitter, such as a DMT modem.

25

The DMT transmitter typically modulates the phase characteristic, or phase, and amplitude of the

carrier signals using an Inverse Fast Fourier Transform (IFFT) to generate a time domain signal, or transmission signal, that represents the input signal. The DMT transmitter transmits the transmission signal, which is a linear combination of the multiple carriers, to a DMT receiver over the communication channel.

5 The phase and amplitude of the carrier signals of DMT transmission signal can be considered random because the phase and amplitude result from the modulation of an arbitrary sequence of input data bits comprising the transmitted information. Therefore, under the condition that the modulated data bit stream is random, the DMT transmission signal can be approximated as having a Gaussian probability distribution. A bit scrambler is often used in the DMT transmitter to scramble
10 the input data bits before the bits are modulated to assure that the transmitted data bits are random and, consequently, that the modulation of those bits produces a DMT transmission signal with a Gaussian probability distribution.

With an appropriate allocation of transmit power levels to the carriers or sub-channels, such a system provides a desirable performance. Further, generating a transmission signal with a Gaussian
15 probability distribution is important in order to transmit a transmission signal with a low peak-to-average ratio (PAR), or peak-to-average power ratio. The PAR of a transmission signal is the ratio of the instantaneous peak value (i.e., maximum magnitude) of a signal parameter (e.g., voltage, current, phase, frequency, power) to the time-averaged value of the signal parameter. In DMT
20 systems, the PAR of the transmitted signal is determined by the probability of the random transmission signal reaching a certain peak voltage during the time interval required for a certain number of symbols. An example of the PAR of a transmission signal transmitted from a DMT transmitter is 14.5 dB, which is equivalent to having a $1\text{E-}7$ probability of clipping. The PAR of a

transmission signal transmitted and received in a DMT communication system is an important consideration in the design of the DMT communication system because the PAR of a signal affects the communication system's total power consumption and component linearity requirements of the system.

5 If the phase of the modulated carriers is not random, then the PAR can increase greatly.

Examples of cases where the phases of the modulated carrier signals are not random are when bit scramblers are not used, multiple carrier signals are used to modulate the same input data bits, and the constellation maps, which are mappings of input data bits to the phase of a carrier signal, used for modulation are not random enough (i.e., a zero value for a data bit corresponds to a 90 degree phase characteristic of the DMT carrier signal and a one value for a data bit corresponds to a -90 degree phase characteristic of the DMT carrier signal). An increased PAR can result in a system with high power consumption and/or with high probability of clipping the transmission signal. Thus, there remains a need for a system and method that can effectively scramble the phase of the modulated carrier signals in order to provide a low PAR for the transmission signal.

15 Summary of the Invention

The present invention features a system and method that scrambles the phase characteristics of the modulated carrier signals in a transmission signal. In one aspect, a value is associated with each carrier signal. A phase shift is computed for each carrier signal based on the value associated with that carrier signal. The value is determined independently of any input bit value carried by that carrier signal. The phase shift computed for each carrier signal is combined with the phase characteristic of that carrier signal to substantially scramble the phase characteristics of the carrier signals.

In one embodiment, the input bit stream is modulated onto the carrier signals having the substantially scrambled phase characteristic to produce a transmission signal with a reduced peak-to-average power ratio (PAR). The value is derived from a predetermined parameter, such as a random number generator, a carrier number, a DMT symbol count, a superframe count, and a hyperframe count. In another embodiment, a predetermined transmission signal is transmitted when the amplitude of the transmission signal exceeds a certain level.

In another aspect, the invention features a method wherein a value is associated with each carrier signal. The value is determined independently of any input bit value carried by that carrier signal. A phase shift for each carrier signal is computed based on the value associated with that carrier signal. The transmission signal is demodulated using the phase shift computed for each carrier signal.

In another aspect, the invention features a system comprising a phase scrambler that computes a phase shift for each carrier signal based on a value associated with that carrier signal. The phase scrambler also combines the phase shift computed for each carrier signal with the phase characteristic of that carrier signal to substantially scramble the phase characteristic of the carrier signals. In one embodiment, a modulator, in communication with the phase scrambler, modulates bits of an input signal onto the carrier signals having the substantially scrambled phase characteristics to produce a transmission signal with a reduced PAR.

Description of the Drawings

The invention is pointed out with particularity in the appended claims. The advantages of the invention described above, as well as further advantages of the invention, may be better understood

by reference to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a block diagram of an embodiment of a digital subscriber line communications system including a DMT (discrete multitone modulation) transceiver, in communication with a remote transceiver, having a phase scrambler for substantially scrambling the phase characteristics of carrier signals; and

Fig. 2 is a flow diagram of an embodiment of a process for scrambling the phase characteristics of the carrier signals in a transmission signal.

Detailed Description

Fig. 1 shows a digital subscriber line (DSL) communication system 2 including a discrete multitone (DMT) transceiver 10 in communication with a remote transceiver 14 over a communication channel 18 using a transmission signal 38 having a plurality of carrier signals. The DMT transceiver 10 includes a DMT transmitter 22 and a DMT receiver 26. The remote transceiver 14 includes a transmitter 30 and a receiver 34. Although described with respect to discrete multitone modulation, the principles of the invention apply also to other types of multicarrier modulation, such as, but not limited to, orthogonally multiplexed quadrature amplitude modulation (OQAM), discrete wavelet multitone (DWTM) modulation, and orthogonal frequency division multiplexing (OFDM).

The communication channel 18 provides a downstream transmission path from the DMT transmitter 22 to the remote receiver 34, and an upstream transmission path from the remote transmitter 30 to the DMT receiver 26. In one embodiment, the communication channel 18 is a pair of twisted wires of a telephone subscriber line. In other embodiments, the communication channel 18 can be a fiber optic wire, a quad cable, consisting of two pairs of twisted wires, or a quad cable

that is one of a star quad cable, a Dieselhorst-Martin quad cable, and the like. In a wireless communication system wherein the transceivers 10, 14 are wireless modems, the communication channel 18 is the air through which the transmission signal 38 travels between the transceivers 10, 14.

5 By way of example, the DMT transmitter 22 shown in Fig. 1 includes a quadrature amplitude modulation (QAM) encoder 42, a modulator 46, a bit allocation table (BAT) 44, and a phase scrambler 66. The DMT transmitter 22 can also include a bit scrambler 74, as described further below. The remote transmitter 30 of the remote transceiver 14 comprises equivalent components as the DMT transmitter 22. Although this embodiment specifies a detailed description of the DMT
10 transmitter 22, the inventive concepts apply also to the receivers 34, 36 which have similar components to that of the DMT transmitter 22, but perform inverse functions in a reverse order.

The QAM encoder 42 has a single input for receiving an input serial data bit stream 54 and multiple parallel outputs to transmit QAM symbols 58 generated by the QAM encoder 42 from the bit stream 54. In general, the QAM encoder 42 maps the input serial bit-stream 54 in the time
15 domain into parallel QAM symbols 58 in the frequency domain. In particular, the QAM encoder 42 maps the input serial data bit stream 54 into N parallel quadrature amplitude modulation (QAM) constellation points 58, or QAM symbols 58, where N represents the number of carrier signals generated by the modulator 46. The BAT 44 is in communication with the QAM encoder 42 to specify the number of bits carried by each carrier signal. The QAM symbols 58 represent the
20 amplitude and the phase characteristic of each carrier signal.

The modulator 46 provides functionality associated with the DMT modulation and transforms the QAM symbols 58 into DMT symbols 70 each comprised of a plurality of time-

domain samples. The modulator 46 modulates each carrier signal with a different QAM symbol 58. As a result of this modulation, carrier signals have phase and amplitude characteristics based on the QAM symbol 58 and therefore based on the input-bit stream 54. In particular, the modulator 46 uses an inverse fast Fourier transform (IFFT) to change the QAM symbols 58 into a transmission signal 38 comprised of a sequence of DMT symbols 70. The modulator 46 changes the QAM symbols 58 into DMT symbols 70 through modulation of the carrier signals. In another embodiment, the modulator 46 uses the inverse discrete Fourier transform (IDFT) to change the QAM symbols 58 into DMT symbols 70. In one embodiment, a pilot tone is included in the transmission signal 38 to provide a reference signal for coherent demodulation of the carrier signals in the remote receiver 34 during reception of the transmission signal 38.

The modulator 46 also includes a phase scrambler 66 that combines a phase shift computed for each QAM-modulated carrier signal with the phase characteristic of that carrier signal. Combining phase shifts with phase characteristics, in accordance with the principles of the invention, substantially scrambles the phase characteristics of the carrier signals in the transmission signal 38. By scrambling the phase characteristics of the carrier signals, the resulting transmission signal 38 has a substantially minimized peak-to-average (PAR) power ratio. The phase scrambler 66 can be part of or external to the modulator 46. Other embodiments of the phase scrambler 66 include, but are not limited to, a software program that is stored in local memory and is executed on the modulator 46, a digital signal processor (DSP) capable of performing mathematical functions and algorithms, and the like. The remote receiver 34 similarly includes a phase scrambler 66' for use when demodulating carrier signals that have had their phase characteristics adjusted by the phase scrambler 66 of the DMT transceiver 10.

To compute a phase shift for each carrier signal, the phase scrambler 66 associates one or more values with that carrier signal. The phase scrambler 66 determines each value for a carrier signal independently of the QAM symbols 58, and, therefore, independently of the bit value(s) modulated onto the carrier signal. The actual value(s) that the phase scrambler 66 associates with each carrier signal can be derived from one or more predefined parameters, such as a pseudo-random number generator (pseudo-RNG), a DMT carrier number, a DMT symbol count, a DMT superframe count, a DMT hyperframe count, and the like, as described in more detail below. Irrespective of the technique used to produce each value, the same technique is used by the DMT transmitter 22 and the remote receiver 34 so that the value associated with a given carrier signal is known at both ends of the communication channel 18.

The phase scrambler 66 then solves a predetermined equation to compute a phase shift for the carrier signal, using the value(s) associated with that carrier signal as input that effects the output of the equation. Any equation suitable for computing phase shifts can be used to compute the phase shifts. When the equation is independent of the bit values of the input serial bit stream 54, the computed phase shifts are also independent of such bit values.

In one embodiment (shown in phantom), the DMT transmitter 22 includes a bit scrambler 74, which receives the input serial bit stream 54 and outputs data bits 76 that are substantially scrambled. The substantially scrambled bits 76 are then passed to the QAM encoder 42. When the bit scrambler 74 is included in the DMT transmitter 22, the operation of the phase scrambler 66 further assures that the transmission signal 38 has a Gaussian probability distribution and, therefore, a substantially minimized PAR.

Fig. 2 shows embodiments of a process used by the DMT transmitter 22 for adjusting the phase characteristic of each carrier signal and combining these carrier signals to produce the transmission signal 38. The DMT transmitter 22 generates (step 100) a value that is associated with a carrier signal. Because the value is being used to alter the phase characteristics of the carrier signal, both the DMT transmitter 22 and the remote receiver 34 must recognize the value as being associated with the carrier signal. Either the DMT transmitter 22 and the remote receiver 34 independently derive the associated value, or one informs the other of the associated value. For example, in one embodiment the DMT transmitter 22 can derive the value from a pseudo-RNG and then transmit the generated value to the remote receiver 34. In another embodiment, the remote receiver 34 similarly derives the value from the same pseudo-RNG and the same seed as used by the transmitter (i.e., the transmitter pseudo-RNG produces the same series of random numbers as the receiver pseudo-RNG).

As another example, the DMT transmitter 22 and the remote receiver 34 can each maintain a symbol counter for counting DMT symbols. The DMT transmitter 22 increments its symbol counter upon transmitting a DMT symbol; the remote receiver 34 upon receipt. Thus, when the DMT transmitter 22 and the remote receiver 34 both use the symbol count as a value for computing phase shifts, both the DMT transmitter 22 and remote receiver 34 “know” that the value is associated with a particular DMT symbol and with each carrier signal of that DMT symbol.

Values can also be derived from other types of predefined parameters. For example, if the predefined parameter is the DMT carrier number, then the value associated with a particular carrier signal is the carrier number of that signal within the DMT symbol. The number of a carrier signal represents the location of the frequency of the carrier signal relative to the frequency of other carrier

signals within a DMT symbol. For example, in one embodiment the DSL communication system 2 provides 256 carrier signals, each separated by a frequency of 4.3125 kHz and spanning the frequency bandwidth from 0 kHz to 1104 kHz. The DMT transmitter 22 numbers the carrier signals from 0 to 255. Therefore, "DMT carrier number 50" represents the 51st DMT carrier signal which is located at the frequency of 215.625 kHz (i.e., 51×4.3125 kHz).

Again, the DMT transmitter 22 and the remote receiver 34 can know the value that is associated with the carrier signal because both the DMT transmitter 22 and the remote receiver 34 use the same predefined parameter (here, the DMT carrier number) to make the value-carrier signal association. In other embodiments (as exemplified above with the transmitter pseudo-RNG), the DMT transmitter 22 can transmit the value to the remote receiver 34 (or vice versa) over the communication channel 18.

In other embodiments, other predefined parameters can be used in conjunction with the symbol count. One example of such a predefined parameter is the superframe count that increments by one every 69 DMT symbols. One exemplary implementation that achieves the superframe counter is to perform a modulo 68 operation on the symbol count. As another example, the DMT transmitter 22 can maintain a hyperframe counter for counting hyperframes. An exemplary implementation of the hyperframe count is to perform a modulo 255 operation on the superframe count. Thus, the hyperframe count increments by one each time the superframe count reaches 255.

Accordingly, it is seen that some predefined parameters produce values that vary from carrier signal to carrier signal. For example, when the predefined parameter is the DMT carrier number, values vary based on the frequency of the carrier signal. As another example, the pseudo-RNG generates a new random value for each carrier signal.

Other predefined parameters produce values that vary from DMT symbol 70 to DMT symbol 70. For example, when the predefined parameter is the symbol count, the superframe count, or hyperframe count, values vary based on the numerical position of the DMT symbol 70 within a sequence of symbols, superframes, or hyperframes. Predefined parameters such as the pseudo-RNG, symbol count, superframe count, and superframe can also be understood to be parameters that vary values over time. Any one or combination of the predefined parameters can provide values for input to the equation that computes a phase shift for a given carrier signal.

In one embodiment, the phase scrambling is used to avoid clipping of the transmission signal on a DMT symbol 70 by DMT symbol 70 basis. In this embodiment, the DMT transmitter 22 uses a value based on a predefined parameter that varies over time, such as the symbol count, to compute the phase shift. It is to be understood that other types of predefined parameters that vary the values associated with carrier signals can be used to practice the principles of the invention. As described above, the transceivers 10, 14 may communicate (step 110) the values to synchronize their use in modulating and demodulating the carrier signals.

The DMT transmitter 22 then computes (step 115) the phase shift that is used to adjust the phase characteristic of each carrier signal. The amount of the phase shift combined with the phase characteristic of each QAM-modulated carrier signal depends upon the equation used and the one or more values associated with that carrier signal.

The DMT transmitter 22 then combines (step 120) the phase shift computed for each carrier signal with the phase characteristic of that carrier signal. By scrambling the phase characteristics of the carrier signals, the phase scrambler 66 reduces (with respect to unscrambled phase characteristics) the combined PAR of the plurality of carrier signals and, consequently, the

transmission signal 38. The following three phase shifting examples, PS #1 – PS #3, illustrate methods used by the phase scrambler 66 to combine a computed phase shift to the phase characteristic of each carrier signal.

Phase Shifting Example #1

Phase shifting example #1 (PS #1) corresponds to adjusting the phase characteristic of the QAM-modulated carrier signal associated with a carrier number N by $N \times \frac{\pi}{3}$, modulo (mod) 2π . In this example, a carrier signal having a carrier number N equal to 50 has a phase shift added to the phase characteristic of that carrier signal equal to $50 \times \frac{\pi}{3} \pmod{2\pi} = \frac{2}{3}\pi$. The carrier signal with a carrier number N equal to 51 has a phase shift added to the phase characteristic of that carrier signal equal to $51 \times \frac{\pi}{3} \pmod{2\pi} = \pi$. The carrier signal with a carrier number N equal to 0 has no phase shift added to the phase characteristic of that carrier signal.

Phase Shifting Example #2

Phase shifting example #2 (PS #2) corresponds to adjusting the phase characteristic of the QAM-modulated carrier signal associated with a carrier number N by $(N + M) \times \frac{\pi}{4}$, mod 2π , where M is the symbol count. In this example, a carrier signal having a carrier number N equal to 50 on DMT symbol count M equal to 8 has a phase shift added to the phase characteristic of that carrier signal equal to $(50 + 8) \times \frac{\pi}{4} \pmod{2\pi} = \frac{\pi}{2}$. The carrier signal with the same carrier number N equal to 50 on the next DMT symbol count M equal to 9 has a phase shift added to the phase characteristic of that carrier signal equal to $(50 + 9) \times \frac{\pi}{4} \pmod{2\pi} = \frac{3\pi}{4}$.

Phase Shifting Example #3

Phase shifting example #3 (PS #3) corresponds to adjusting the phase characteristic of the

QAM-modulated carrier signal associated with a carrier number N by $(X_N) \times \frac{\pi}{6}, \text{ mod } 2\pi$, where X_N

is an array of N pseudo-random numbers. In this example, a carrier signal having a carrier number

5 N equal to 5 and X_N equal to [3, 8, 1, 4, 9, 5, ...] has a phase shift added to the phase characteristic

of the carrier signal that is equal to $(9) \times \frac{\pi}{6} (\text{mod } 2\pi) = \frac{\pi}{3}$. (Note that 9 is the 5th value in X_N .) The

carrier signal with a carrier number N equal to 6 has a phase shift added to the phase characteristic of

the carrier signal equal to $(5) \times \frac{\pi}{6} (\text{mod } 2\pi) = \frac{5\pi}{6}$.

It is to be understood that additional and/or different phase shifting techniques can be used by

10 the phase scrambler 66, and that PS #1, #2, and #3 are merely illustrative examples of the principles

of the invention. The DMT transmitter 22 then combines (step 130) the carrier signals to form the

transmission signal 38. If the transmission signal is not clipped, as described below, the DMT

transmitter 22 consequently transmits (step 160) the transmission signal 38 to the remote receiver 34.

Clipping of Transmission Signals

15 A transmission signal 38 that has high peak values of voltage (i.e., a high PAR) can induce

non-linear distortion in the DMT transmitter 22 and the communication channel 18. One form of

this non-linear distortion of the transmission signal 38 that may occur is the limitation of the

amplitude of the transmission signal 38 (i.e., clipping). For example, a particular DMT symbol 70

clips in the time domain when one or more time domain samples in that DMT symbol 70 are larger

20 than the maximum allowed digital value for the DMT symbols 70. In multicarrier communication

systems when clipping occurs, the transmission signal 38 does not accurately represent the input serial data bit signal 54.

In one embodiment, the DSL communication system 2 avoids the clipping of the transmission signal 38 on a DMT symbol 70 by DMT symbol 70 basis. The DMT transmitter 22 detects (step 140) the clipping of the transmission signal 38. If a particular DMT symbol 70 clips in the time domain to produce a clipped transmission signal 38, the DMT transmitter 22 substitutes (step 150) a predefined transmission signal 78 for the clipped transmission signal 38.

The predefined transmission signal 78 has the same duration as a DMT symbol 70 (e.g., 250 ms) in order to maintain symbol timing between the DMT transmitter 22 and the remote receiver 34.

The predefined transmission signal 78 is not based on (i.e., independent of) the modulated input data bit stream 54; it is a bit value pattern that is recognized by the remote receiver 34 as a substituted signal. In one embodiment, the predefined transmission signal 78 is a known pseudo-random sequence pattern that is easily detected by the remote receiver 34. In another embodiment, the predefined transmission signal 78 is an “all zeros” signal, which is a zero voltage signal produced at the DMT transmitter 22 output (i.e., zero volts modulated on all the carrier signals). In addition to easy detection by the remote receiver 34, the zero voltage signal reduces the power consumption of the DMT transmitter 22 when delivered by the DMT transmitter 22. Further, a pilot tone is included in the predefined transmission signal 78 to provide a reference signal for coherent demodulation of the carrier signals in the remote receiver 34 during reception of the predefined transmission signal 78.

After the remote receiver 34 receives the transmission signal 38, the remote receiver 34 determines if the transmission signal 38 is equivalent to the predefined transmission signal 78. In

one embodiment, when the remote receiver 34 identifies the predefined transmission signal 78, the remote receiver 34 ignores (i.e., discards) the predefined transmission signal 78.

Following the transmission of the predefined transmission signal 78, the phase scrambler 66 shifts (step 120) the phase characteristic of the QAM-modulated carrier signals (based on one of the predefined parameters that varies over time). For example, consider that a set of QAM symbols 58 produces a DMT symbol 70 comprising a plurality of time domain samples, and that one of the time domain samples is larger than the maximum allowed digital value for the DMT symbol 70. Therefore, because the transmission signal 38 would be clipped when sent to the remote receiver 34, the DMT transmitter 22 sends the predefined transmission signal 78 instead.

After transmission of the predefined transmission signal 78, the DMT transmitter 22 again attempts to send the same bit values that produced the clipped transmission signal 38 in a subsequent DMT symbol 70'. Because the generation of phase shifts in this embodiment is based on values that vary over time, the phase shifts computed for the subsequent DMT symbol 70' are different than those that were previously computed for the DMT symbol 70 with the clipped time domain sample. These different phase shifts are combined to the phase characteristics of the modulated carrier signals to produce carrier signals of the subsequent DMT symbol 70' with different phase characteristics than the carrier signals of the DMT symbol 70 with the clipped time domain sample.

DMT communication systems 2 infrequently produce transmission signals 38 that clip (e.g., approximately one clip every 10^7 time domain samples 70). However, if the subsequent DMT symbol 70' includes a time domain sample that clips, then the predefined transmission signal 78 is again transmitted (step 150) to the remote receiver 34 instead of the clipped transmission signal 38. The clipping time domain sample may be on the same or on a different carrier signal than the

previously clipped DMT symbol 70. The DMT transmitter 22 repeats the transmission of the predefined transmission signal 78 until the DMT transmitter 22 produces a subsequent DMT symbol 70' that is not clipped. When the DMT transmitter 22 produces a DMT symbol 70' that is not clipped, the DTM transmitter 22 transmits (step 160) the transmission signal 38 to the remote receiver 34. The probability of a DMT symbol 70 producing a transmission signal 38 that clips in the time domain depends on the PAR of the transmission signal 38.

For example, the following phase shifting example, PST #4, illustrates the method used by the phase scrambler 66 to combine a different phase shift to the phase characteristic of each carrier signal to avoid the clipping of the transmission signal 38.

10 Phase Shifting Example #4

Phase shifting example #4 (PS #4) corresponds to adjusting the phase characteristic of the carrier signal associated with a carrier number N by $\frac{\pi}{3} \times (M + N)$, mod 2π , where M is the DMT symbol count. In this example, if the DMT symbol 70 clips when the DMT symbol count M equals 5, the predefined transmission signal 78 is transmitted instead of the current clipped transmission signal 38. On the following DMT symbol period, the DMT count M equals 6, thereby causing a different set of time domain samples to be generated for the subsequent DMT symbol 70', although the QAM symbols 58 used to produce both DMT symbols 70, 70' are the same.

If this different set of time domain samples (and consequently the transmission signal 38) is not clipped, the DMT transmitter 22 sends the transmission signal 38. If one of the time domain samples in the different set of time domain samples 70 (and consequently the transmission signal 38) is clipped, then the DMT transmitter 22 sends the predefined transmission signal 78 again. The process continues until a DMT symbol 70 is produced without a time domain sample 70 that is

clipped. In one embodiment, the transmitter 22 stops attempting to produce a non-clipped DMT symbol 70' for the particular set of QAM symbols 58 after generating a predetermined number of clipped DMT symbols 70'. At that moment, the transmitter 22 can transmit the most recently produced clipped DMT symbol 70' or the predetermined transmission signal 78.

5 The PAR of the DSL communication system 2 is reduced because the predefined transmission signal 78 is sent instead of the transmission signal 38 when the DMT symbol 70 clips. For example, a DMT communication system 2 that normally has a clipping probability of 10^{-7} for the time domain transmission signal 38 can therefore operate with a 10^{-5} probability of clipping and a lower PAR equal to 12.8 dB (as compared to 14.5 dB). When operating at a 10^{-5} probability of clipping, assuming a DMT symbol 70 has 512 time-domain samples 70, the DMT transmitter 22 experiences one clipped DMT symbol 70 out of every $\frac{10^5}{512}$, or 195 DMT symbols 70. This results in the predefined (non-data carrying) transmission signal 78 being transmitted, on average, once every 195 DMT symbols. Although increasing the probability of clipping to 10^{-5} results in approximately a 0.5% (1/195) decrease in throughput, the PAR of the transmission signal 38 is reduced by 1.7 dB, which reduces transmitter complexity in the form of power consumption and component linearity.

10 While the invention has been shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the following claims. For example, although the specification uses DSL to describe the invention, it is to be understood that various form of DSL can be used, e.g., ADSL, VDSL, SDSL, HDSL, HDSL2, or SHDSL. It is also to be understood that the principles of the invention apply to

various types of applications transported over DSL systems (e.g., telecommuting, video conferencing, high speed Internet access, video-on demand).

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Claims

What is claimed is:

- 1 1. In a multicarrier modulation system including a first transceiver in communication with a
2 second transceiver using a transmission signal having a plurality of carrier signals for
3 modulating an input bit stream, each carrier signal having a phase characteristic associated
4 with the input bit stream, a method for scrambling the phase characteristics of the carrier
5 signals comprising:
6 associating each carrier signal with a value determined independently of any input bit
7 value carried by that carrier signal;
8 computing a phase shift for each carrier signal based on the value associated with that
9 carrier signal; and
10 combining the phase shift computed for each carrier signal with the phase
11 characteristic of that carrier signal so as to substantially scramble the phase characteristics
12 of the plurality of carrier signals.
- 1 2. The method of claim 1 further comprising modulating bits of the input bit stream onto the
2 carrier signals having the substantially scrambled phase characteristics to produce a
3 transmission signal with a reduced peak-to-average power ratio (PAR).
- 1 3. The method of claim 1 further comprising independently deriving the value associated with
2 each carrier signal at each transceiver.

- 1 4. The method of claim 1 further comprising transmitting the value associated with each carrier
2 signal from one transceiver to the other transceiver.
- 1 5. The method of claim 1 further comprising maintaining synchronization between the
2 transceivers using the value associated with each carrier signal.
- 1 6. The method of claim 1 wherein the value varies with each carrier signal.
- 1 7. The method of claim 1 wherein the value varies with each DMT symbol.
- 1 8. The method of claim 1 wherein the value is derived from a predetermined parameter.
9. The method of claim 8 wherein the predefined parameter is a carrier number.
10. The method of claim 8 wherein the predefined parameter is a symbol count.
11. The method of claim 8 wherein the predefined parameter is a hyperframe count.
12. The method of claim 8 wherein the predefined parameter is a superframe count.
13. The method of claim 1 further comprising scrambling the bits of the input bit stream.
- 1 14. The method of claim 1 further comprising transmitting a predetermined transmission signal
2 when the amplitude of the transmission signal exceeds a certain level.
- 1 15. The method of claim 14 wherein the predetermined transmission signal comprises a
2 predetermined pattern of bits.

- 1 16. The method of claim 14 wherein the predetermined transmission signal comprises a pilot
2 tone.
- 1 17. The method of claim 16 wherein the pilot tone is used to maintain timing synchronization
2 between the first transceiver and the second transceiver.
- 1 18. The method of claim 15 wherein each bit value in the predetermined pattern of bits is a zero
2 value.
- 1 19. The method of claim 15 wherein the predetermined pattern of bits is a pseudo-random
2 sequence pattern.
- 1 20. In a multicarrier modulation system including a first transceiver in communication with a
2 second transceiver using a transmission signal having a plurality of carrier signals for
3 modulating an input bit stream, each carrier signal having a phase characteristic with the
4 input bit stream, a method for scrambling the phase characteristics of the carrier signals
5 comprising:
6 associating each carrier signal with a value determined independently of any input bit
7 value carried by that carrier signal;
8 computing a phase shift for each carrier signal based on the value associated with that
9 carrier signal; and
10 demodulating the transmission signal using the phase shift computed for each carrier
11 signal.

- 1 21. The method of claim 20 further comprising independently deriving the value associated with
2 each carrier signal at each transceiver.
- 1 22. The method of claim 20 further comprising transmitting the value associated with each
2 carrier signal from one transceiver to the other transceiver.
- 1 23. The method of claim 20 further comprising maintaining synchronization between the
2 transceivers using the value associated with each carrier signal.
- 1 24. The method of claim 20 wherein the value varies with each carrier signal.
- 1 25. The method of claim 20 wherein the value varies with each DMT symbol.
- 1 26. The method of claim 20 wherein the value is derived from a predetermined parameter.
- 1 27. The method of claim 26 wherein the predefined parameter is a carrier number.
- 1 28. The method of claim 26 wherein the predefined parameter is a symbol count.
- 1 29. The method of claim 26 wherein the predefined parameter is a hyperframe count.
- 1 30. The method of claim 26 wherein the predefined parameter is a superframe count.
- 1 31. The method of claim 20 further comprising receiving a predetermined transmission when the
2 amplitude of the transmission signal exceeds a certain level.
- 1 32. The method of claim 31 wherein the predetermined transmission signal comprises a
2 predetermined pattern of bits.

- 1 33. The method of claim 31 wherein the predetermined transmission signal comprises a pilot
2 tone.
- 1 34. The method of claim 33 wherein the pilot tone is used to maintain timing synchronization
2 between the first transceiver and the second transceiver.
- 1 35. The method of claim 32 wherein each bit value in the predetermined pattern of bits is a zero
2 value.
- 1 36. The method of claim 32 wherein the predetermined pattern of bits is a pseudo-random
2 sequence pattern.
- 1 37. A transceiver for communicating over a communication channel using a transmission signal
2 having a plurality of carrier signals, each carrier signal having a phase characteristic, the
3 transceiver comprising:
4 a phase scrambler computing a phase shift for each carrier signal based on a value
5 associated with that carrier signal and combining the phase shift computed for each carrier
6 signal with the phase characteristic of that carrier signal so as to substantially scramble the
7 phase characteristics of the plurality of carrier signals.
- 1 38. The transceiver of claim 37 further comprising a modulator in communication with the phase
2 scrambler, the modulator modulating bits of an input signal onto the carrier signals having
3 the substantially scrambled phase characteristics to produce a transmission signal with a
4 reduced PAR.

1 39. In a multicarrier modulation system, a method for communicating over a communication
2 channel, comprising:
3 receiving over the communication channel a transmission signal comprised of a
4 sequence of DMT symbols that each have a bit-value pattern;
5 comparing the bit-value pattern of each received DMT symbol with a predetermined
6 bit value pattern;
7 discarding a given one of the received DMT symbols in the sequence of DMT
8 symbols if the bit-value pattern of that DMT symbol matches the predetermined bit-value
9 pattern, otherwise demodulating that DMT symbol.

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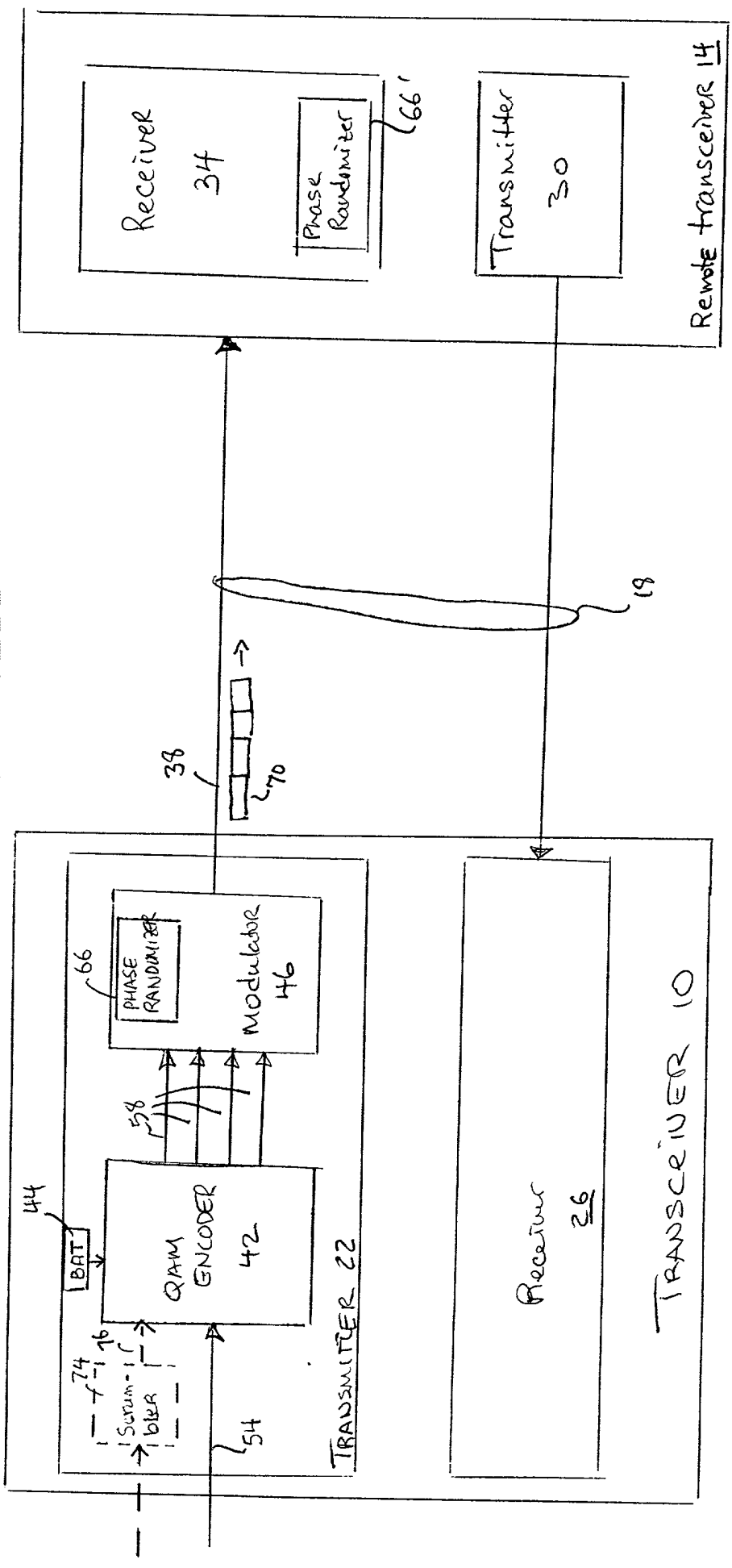


FIG. 1

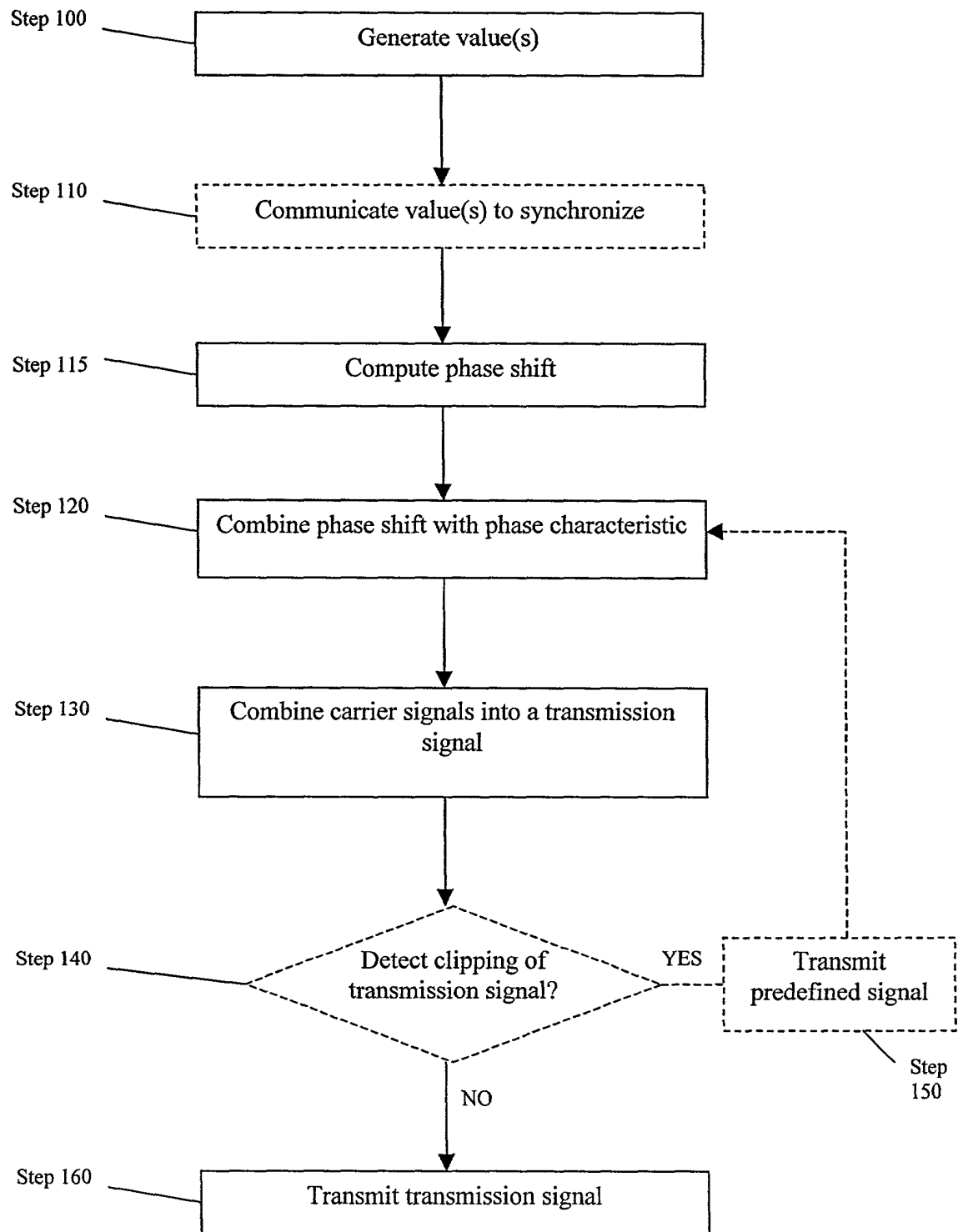


FIG. 2

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	First Named Inventor	Tzannes
	COMPLETE IF KNOWN	
	Application Serial Number	Not Yet Assigned
	Filing Date	Herewith
	Group Art Unit	Not Yet Assigned
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As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

A System And Method For Scrambling The Phase Of The Carriers In A Multicarrier Communications System

(Title of the Invention)

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I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose to the Patent Office all information known by me to be material to patentability as defined in 37 CFR 1.56.

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Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached?	
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60/164,134	11/09/1999	<input type="checkbox"/> Additional provisional application serial numbers are listed on a supplemental priority data sheet attached hereto.

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I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c), of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Serial Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

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Name of Additional Joint Inventor, if any:		<input type="checkbox"/> A petition has been filed for this unsigned inventor					
Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature						Date	
Residence	City		State		Country		Citizenship
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